Design for the Lift Platform Humanoid Climb Assisting Unit of the Space Launch Site

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Abstract: Humanoid climb assisting unit (HCAU) is a key mechanism for the lift platform to adjust its height-level of the space launch site. It is widely used for lift platforms of launch towers, service towers, vertical assembly test building for launch vehicles and that of silos for missiles. In this paper, its working principal is illustrated. The design requirements and terms, design steps and effecting factors are discussed. Three types of HCAU design methods and their calculating formulae are derived. Design examples are presented.

Keywords: Space launch site, lift platform, humanoid climbing mechanism, height-level adjustment.

1. INTRODUCTION

At space launch site, lift platforms are very important ground support equipment wildly used at launch towers, service towers, rocket vertical assembly test building, rocket vibration test towers, rocket engine test benches and silos. Their main functions are fulfilling the tasks to supply working platforms for the personnel related to the operation of hoisting, connecting, testing, filling-up propellant for different carrier rockets and spacecrafts within a large range of vertical height-level positions.

There are many types of mechanism for a lift platform to adjust its height-level, such as by allocating several flanges in different height-level positions for it to connect with, or by using a screw lifting mechanism to change its positions and then to be fixed by assistant insert pins or clamp clips, etc. But all of them can not continuously adjust the height-level position of the lift platform during a large range of height-level distance except the HCAU mechanism. So, HCAU is the most widely used one at the space launch site of our country historically, and it can easily adjust any lift platform separately along the guide rails to get its needed height-level position and allow it to be temporarily stood-by or fasted for a long time to work during the space launching mission [1, 2].

HCAU being a key mechanism for lift platforms is not only because of its function ability, but also its great safety for working under the risk of any leakage of inflammable propellant circumstances. After years of development and application, we find that it is not easy to be designed perfectly even referring to literature about industrial robot mechanical structures. Some of them in use have the defect of inconvenient for the insert-pins to be pulled out or inserted in when the hydraulic cylinders reach their ends, and the others may have the deficiency of disassembly and assembly the ram anchor of the hydraulic cylinder difficultly when it is need to be replaced or repaired. The main reason for these defects is that there have no any ready-made available calculating formulae can be found for the HCAU design at the literature or current designing standards [2-4]. Another reason is that the designing conditions for any HACU design and its designer are definitely different. These make it to be a very complex task relying on various structural conditions and individuals. In this paper, we thoroughly study the principal and working steps of HCAU firstly. Then, we promote some regulations and terms for the HCAU structural design must to be strictly abiding by. Furthermore, we analyze three methods for the HCAU designing in details, and derive out the theoretical formulae for them. In the meantime, several designing examples are presented for each method, and some designing steps are summed up for the designers to reference in addition.

2. WORKING PRINCIPAL OF THE HCAU

Figure **1** illustrates the three main parts which consist of the HCAU and their assembling relationships. There are two HCAUs in Figure **1**. They are linked by the lift platform framework, and should be running in a synchronism manner to adjust the height-level of the lift platform.

Each HCAU consists of tree parts: one fixed part, one driving part and one objective part. The fixed part is a set of fixed guide rails for the lift platform to be able to running along by its wheels. It includes a square

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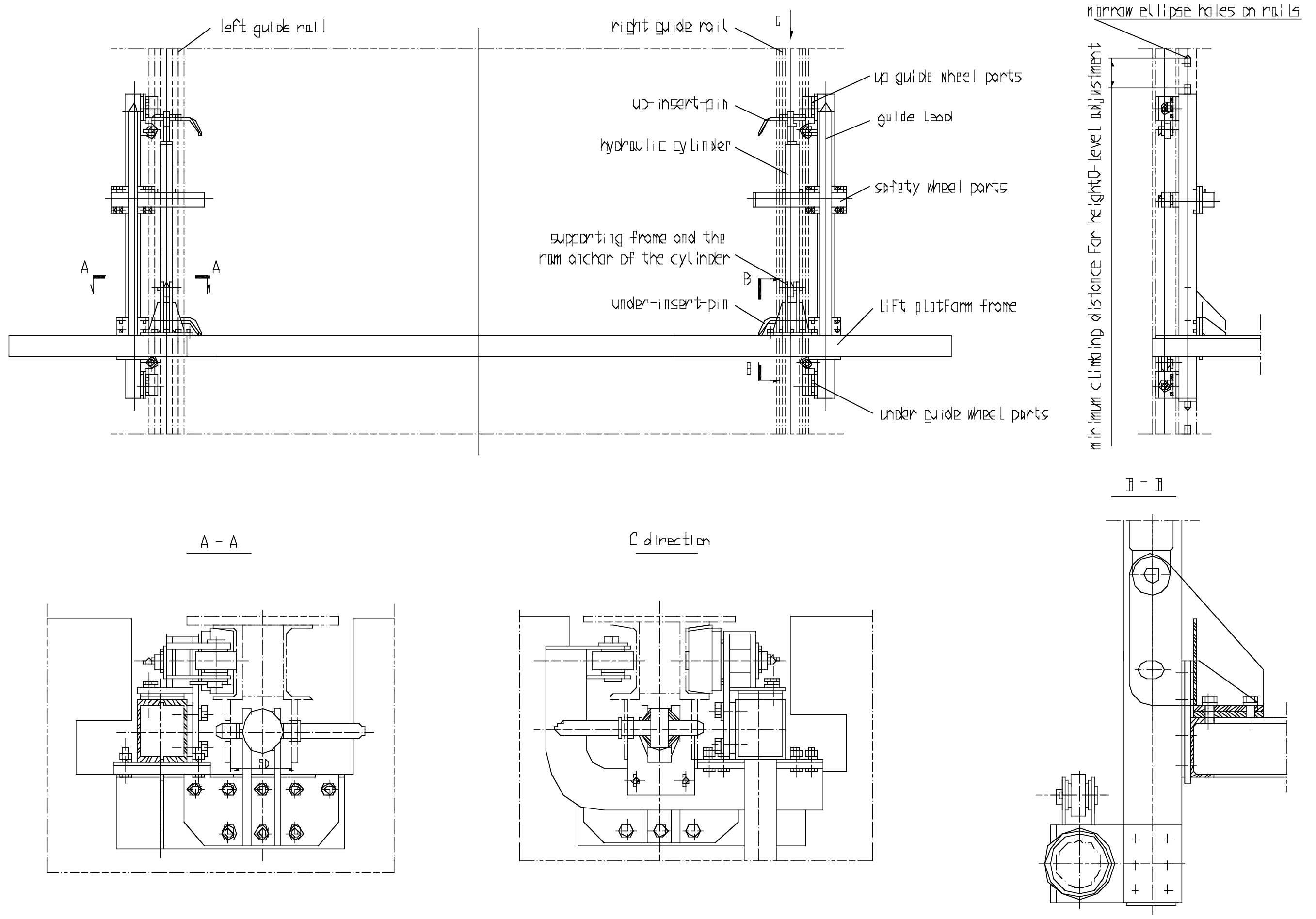

Figure 1: Assembling relationships among the parts of the HCAUs.

shape column and two pieces of steel plates (named the left and the right piece). Every piece of steel plate is designed allocating with many equidistant holes in array. The driving part is a set of components which will be providing the moving power for the lift platform to lift-up or descending-down. It includes one double acting differential hydraulic cylinder and two insert-pins mounting on its both ends. The pin at the cylinder piston rod end we called it the "up-insert-pin". During working, the cylinder can be hinged manually by the up-insert-pin to the holes of both the left and right guide rails to "grasp" them when its rod stretching out or drawing back (similar to the human's arm). The pin at the cylinder base end we called it the "ram anchor", and it is a short pin not longer than the distance between the two pieces of the rail steel plates. The objective part is a set of components located on the lift platform. It includes a cylinder supporting frame and the lift platform supporting under-insert-pin. The supporting frame usually has two pin holes and a bottom flange. The up pin hole is used to link base end of the cylinder by the ram anchor, and the low pin hole is used for inserting the under-insert-pin through the holes of the guide rails to support the lift platform and its load when the lift platform having been moved to its needed height-level working position (similar to the human's foot). The bottom flange is used to tightly mount it onto the lift platform structure frame by bolts.

The working principal of HCAU can be depicted as following: HCAU adjust the height-level of the lift platform by the cylinder reciprocate working cycles. At one cycle, the lift platform can be adjusted at least a minimum distance between two adjacent holes on the guide rails, or at a maximum distance equals to the cylinder stoke length. Continuous cycles, it can be moved to it wanted position. During the processes, the up-insert-pin and under-insert-pin are simultaneously inserted-in or pulled-out by the operators while the wheels mounted on the platform support columns are moving along the guide rails.

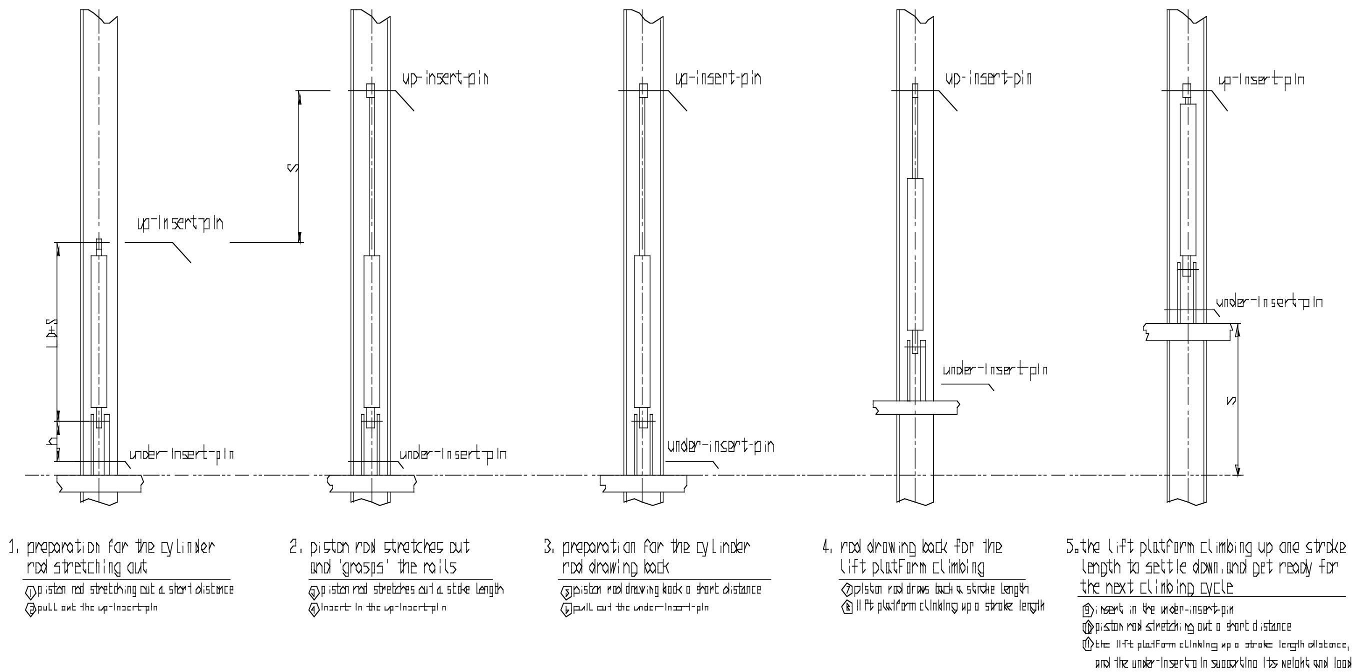

Figure 2: Digraph of one climbing up working cycle of the HCAU for the lift platform height-level adjustment.

Figure **2** illustrates the ascending working steps of HCAU in one cycle. Initially, the lift platform stays at position 1, and the under-insert-pin supports its weight and loads while the up-insert-pin is free of charge. The ascending working cycle steps can be illustrates as following: ⊖ the cylinder rod stretches out a short length to let the up-insert-pin being free of charge and make it can be easily pulled out from the holes at this moment → ⊜ the cylinder rod stretches out to a stroke length, and the operator can easily inserts the up-insert-pin into the matching holes at this new position in the meantime → ⊛ the cylinder rod draws back a short length to make the up-insert-pin burdening the lift platform and its loads and let the under-insert-pin being free of charge, then the operator can easily pulled the under-insert-pin out from the holes at the same time → ④ the cylinder rod draws back further to a stroke length, then the operator can inserts the under-insert-pin into the matching holes at another new position in the meantime → ⑤ the cylinder rod is stretched out a short length to let the under-insert-pin burdening the lift platform and its load and let the up-insert-pin being free of charge. Till now, the lift platform completes a stroke length height-level climbing up distance. Repeating steps ⊖ ~ ⑤, the lift platform can be moved from position 1 to the wanted position 2. If the wire lines and hydraulic hoses are long enough, it can be moved along the rails to adjust its height-level for a long distance.

3. TERMS AND REGULATIONS FOR THE HCAU DESIGN

For any specific mechanical design project, we must analyze its custom demands in detail to obtain its design terms and regulations, and then assign the performance indexes for it. According to the HCAU design scheme illustrated in Figure **1**, we can get the terms and regulations for it as following:

1. The ram anchor of the cylinder can be easily disassembled from or assembled to the supporting frame for the cylinder maintenance or replacement.

2. In order to improve the efficiency of the HCAU working cycle illustrated at Figure **2**, we hope the HCAU can be designed exactly to match the holes when the cylinder is entirely stretches out a stroke length, and be ready for the operator to pull out or insert in the up-insert-pin easily. In this way, we can take advantage of the cylinders whole stroke length at one time.

3. Similar to terms (2), a perfect HCAU design is also needed to have an exact installation length for the cylinder to match the holes when it entirely draws back, and the under-insert-pin of the HCAU can be easily pulled out or inserted efficiently at this point in the same time.

4. In order to easily pull out or insert in the under-insert-pin easily at any height-level position, the wide dimension of the pin holes the on the support frame should be able to compensate the clearance between the wheels and the guide rails and the thickness of the adjustment cousins for the wheels to mount properly.

5. The distance between the adjacent holes on the guide rails (it is also called the step length in height) must meet the minimum lift platform height-level position adjustment accuracy requirements.

3. THEORETICAL ANALYSIS AND FORMULAE DERIVATION

Firstly, in order to meet the terms (5) mentioned above, we induce parameter λ as an inputting index for the HACU design to represent the minimum height-level distance of the holes array on the guide rails. It is usually evaluated to be appropriate for the specific designing project, and often defined as integral times of 50mm or 100mm.

Then, we illustrate the design problem for AHCU as Figure **3**. Here, Point A represents the position of the under-insert-pin where the lift platform is parking at its original height-level. Point B represents the position of the arm anchor of the hydraulic cylinder at its base end. Point C represents the position of the up-insert-pin before the lift platform climbing up, and it is corresponding to the rod end eye ring of the cylinder in its installation length. Point C′ represents the position of the up-insert-pin after the lift platform climbing up a stroke length, and it is corresponding to the rod end eye ring of the cylinder when it stretches out a stroke length. Other symbols in Figure **3** are assigned to indicate the following parameters used for the HACU design:

L_0 ——The structural dead legnth of the cylinder.

S ——Stroke legnth of the cylinder.

$L_0 + S$ ——Installation legnth of the cylinder.

$L_0 + 2S$ ——Stretching out legnth of the cylinder.

h ——Distance between the ram anchor of the cylinder and the supporting under-insert-pin of the lift platform.

The original position of point A is a known height-level after the working place of the lift platform is determined. So does the hydraulic cylinder and its specifications. Then, L_0 is aslo a known parameter.

In ordinary, L_0 is not a number in proportion to λ. But all the points A, B, C and C′ are positions of the three pins corresponding to the holes on the guide rails which are in proportion to λ. So, it is difficult for the designer to find a common divisor proportion to λ among L_0, $h + L_0 + S$ and $h + L_0 + 2S$.

In order to solve this problem, we induce another parameter Δ as a design variable which represents the long size of the holes on the guide rails to compensate the minimum length mismatch among the parameters

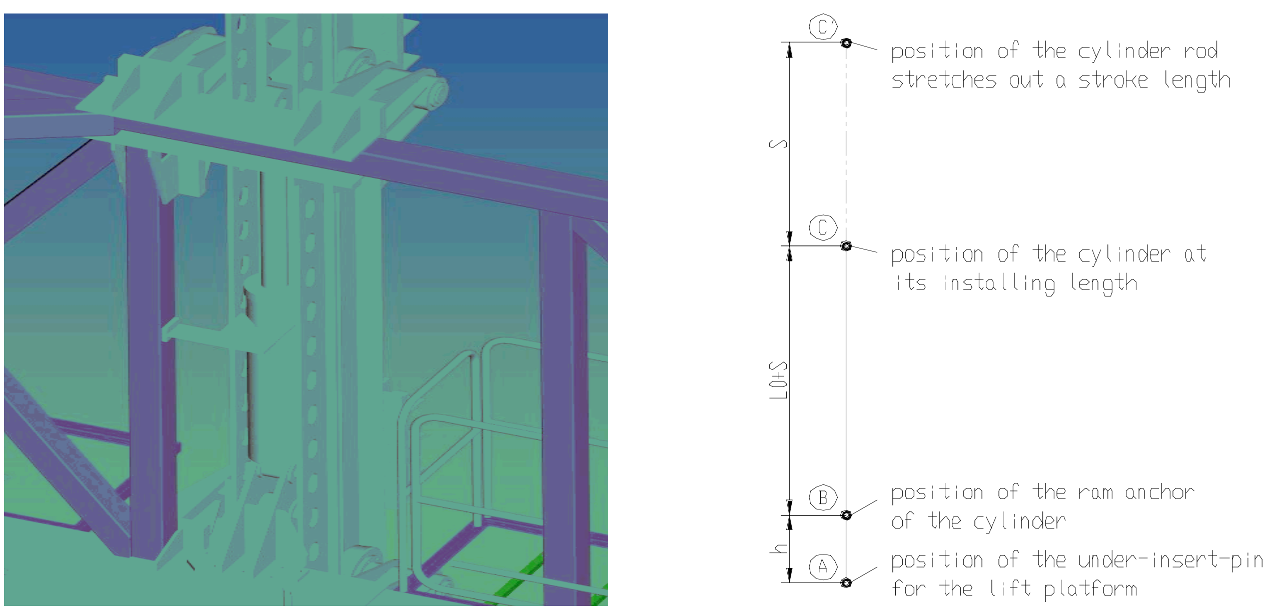

Figure 3: Diagram for theoretical analysis of the HACU.

above. In some times, we may need to adjust parameter Δ in common with h and S to get a perfect solution.

In this way, we convert the design problem to be processes to solve the solution of parameters Δ, h and S to meet the terms and regulations for the HCAU design mentioned above. We can describe it as the following three cases according to the known parameters L_0, λ, $h+L_0+S$, $h+L_0+2S$ and their related equations and inequations:

3.1. Method One: Given λ, L_0, Tuning Points A, B (h), C and C′ to Get Δ and S

In this method, we consider tuning both points B, C by Δ and h to compensate the length mismatch because both the cylinder stretching out length and drawing back length are not in proportion to λ. It can be described by the following inequations:

1. Referring to the Figure **2**, the parameters should obey the following inequation to complying with the term (2) for the HCAU design mentioned at chapter 3:

$$N\lambda \le h+L_0+2S \le N\lambda+\Delta \qquad (3\text{-}1\text{-}1)$$

Here,

N—— an integer equals the quotient of the distance between point A and C′ divided by λ.

2. Referring to the Figure **2**, the parameters should obey the following inequation to complying with the term (3) for the HCAU design mentioned at chapter 3:

$$N_1\lambda-\Delta \le h+L_0+S \le N_1\lambda \qquad (3\text{-}1\text{-}2)$$

Here,

N_1—— an integer equals the quotient of the distance between point A and C divided by λ.

3. Referring to the Figure **2**, the parameters should obey the following inequation to complying with the term (1) for the HCAU design mentioned at chapter 3:

$$n\lambda \le h \le n\lambda+\Delta \qquad (3\text{-}1\text{-}3)$$

Here,

n—— an integer. For compactness, we usally choose n=1.

From inequations (3-1-1) and (3-1-2), we can derive the following inequations:

$$(N-N_1)\lambda \le S \le (N-N_1)\lambda+2\Delta \qquad (3\text{-}1\text{-}4)$$

$$[(2N_1-N)\lambda-L_0-h]/3 \le \Delta \le (2N_1-N)\lambda-L_0-h \qquad (3\text{-}1\text{-}5)$$

Using inequations (3-1-1)~(3-1-5), we can carry out the design processes easily.

If this method and the derived formulae are used to design the HACU, all the holes on the guide rails should be designed as narrow ellipse holes, and be manufactured in arrays at the same distance λ between the adjacent holes. The amount of manufacturing quantity and the costs is very large. For every hole, the long size of it must be bigger or equals to Δ, and the wide size of it must be bigger or equals to the diameter of the pins.

3.2. Method Two: Given λ, L_0, Points A, C, and C′, Tuning Point B (h) to Get Δ and S

In this method, we consider tuning point B by Δ to compensate the length mismatch mentioned above. It can be described by the following equations:

1) Referring to the Figure **2**, the parameters should obey the following equation to complying with the term (2) for the HCAU design mentioned at chapter 3:

$$h+L_0+2S = N\lambda \qquad (3\text{-}2\text{-}1)$$

2) Referring to the Figure **2**, the parameters should obey the following equation to complying with the term (3) for the HCAU design mentioned at chapter 3:

$$h+\Delta+L_0+S = N_1\lambda \qquad (3\text{-}2\text{-}2)$$

3) Referring to the Figure **2**, the parameters should obey the following equation to complying with the term (1) for the HCAU design mentioned at chapter 3:

$$n\lambda-\Delta \le h \le n\lambda \qquad (3\text{-}2\text{-}3)$$

From equations (3-2-1) and (3-2-2), we can derive the following equations:

$$S = (N-N_1)\lambda+\Delta \qquad (3\text{-}2\text{-}4)$$

$$\Delta = \left[(2N_1-N)\lambda-L_0-h\right]/2 \qquad (3\text{-}2\text{-}5)$$

Using equations (3-2-1)~(3-2-5), we can carry out the design processes easily.

If this method and the derived formulae are used to design the HACU, only the holes on the supporting frame are needed to be designed as narrow ellipse holes. The long size of the holes must be bigger or equals to Δ, and the wide size of it must be bigger or equals to the diameter of the pins.

At this case, the holes on the guide rails can just be of round holes manufactured in arrays at the same distance λ between the adjacent holes. The amount of manufacturing quantity and the costs is greatly decreased comparing with method one. For every hole, its diameter must be bigger or equals to that of the pins.

3.3. Method Three: Given λ, L_0, Points A and B (h), Tuning Point C to Get Δ and S

In this method, we consider tuning point C by Δ to compensate the length mismatch mentioned above. It can be described by the following inequations and equations:

1. Referring to the Figure **2**, the parameters should obey the following inequation to complying with the term (2) for the HCAU design mentioned at chapter 3:

$$N\lambda-\Delta\le h+L_0+2S\le N\lambda \quad (3\text{-}3\text{-}1)$$

2. Referring to the Figure **2**, the parameters should obey the following equation to complying with the term (3) for the HCAU design mentioned at chapter 3:

$$h+L_0+S+\Delta=N_1\lambda \quad (3\text{-}3\text{-}2)$$

3. Referring to the Figure **2**, the parameters should obey the following equation to complying with the term (1) for the HCAU design mentioned at chapter 3:

$$h=n\lambda \quad (3\text{-}3\text{-}3)$$

From equations (3-2-1) and (3-2-2), we can derive the following inequations:

$$(N-N_1)\lambda\le S\le(N-N_1)\lambda+\Delta \quad (3\text{-}3\text{-}4)$$

$$\left[(2N_1-N)\lambda-L_0-h\right]/2\le\Delta\le(2N_1-N)\lambda-L_0-h10 \quad (3\text{-}3\text{-}5)$$

Formula (3-3-5) is the same as (3-2-5), Using equations (3-3-1)~(3-3-5), we can carry out the design processes easily.

Using this method, only the hole for the rod end of the cylinder is designed as a narrow ellipse hole. Its long size must be bigger or equals to Δ, and its wide size must be bigger or equals to the diameter of the pins.

At this case, the holes on the guide rails and their manufacturing quantity and the costs are the same as method two.

4. EXAMPLES AND DISCUSSION

4.1. Examples and Discussion on Parameter h

Assuming λ=200mm, L_0=438mm, $N-N_1$=3, N=10, N_1=7, n=1. Then, we can get the solutions for the three methods as following:

As for method one, if we choice h referring to formula (3-1-3), then we can get the limit solutions for this case: if $h=n\lambda$, then $\Delta=54$mm, $S=708$mm. If $h=n\lambda+\Delta$, then $\Delta=40.5$mm, $S=681$mm.

As for method two, if we choice h referring to formula (3-2-3), then we can get the limit solutions for this case: if $h=n\lambda-\Delta$, then $\Delta=162$mm, $S=$ 762mm. If $h=n\lambda$, then $\Delta=81$mm, $S=681$mm. If the ram anchor aims at the mid point of the length Δ of the narrow holes on the supporting frame, that is $h=n\lambda-\Delta/2$, and then $\Delta=108$mm, S=708mm.

For method three, if we choice the position of the up-insert-pin referring to formula (3-3-1), then we can get the limit solutions for this case:

If $h+L_0+2S=N\lambda$, then the up-insert-pin aims at the under center point of the ellipse eye ring hole of the rod of the hydraulic cylinder, and $\Delta=81$mm, $S=681$mm.

If $h+L_0+2S=N\lambda-\Delta$, then the up-insert-pin aims at the top center point of the ellipse eye ring hole of the rod of the hydraulic cylinder. That means Δ just extend L_0 to be times of λ, and $\Delta=162$mm, $S=600$mm.

If $h+L_0+2S=N\lambda-\Delta/2$, then the up-insert-pin aims at the middle point of the ellipse eye ring hole of the rod of the hydraulic cylinder, and $\Delta=108$mm, $S=654$mm.

Comparing the three designing methods, we can find that method one has three parameters to solve.

They are h, Δ and S, and the parameter h is not including in method two or method three.

From all the corresponding formulae and the examples, we can find that parameter h can decrease the length Δ of the narrow holes on the guide rails if it is chosen properly. Method one can get the smallest solution of Δ than that of method two or method three.

Further more, if we let $h \le 0$, then an alternative structure for HACU is introduced. At this case, we must split the central supporting frame with one under-insert-pin into two side supporting frames with two under-insert-pins.

4.2. Discussion on the Tolerance for Δ, S

For any case, the calculated parameter Δ using formula (3-1-5) or (3-2-5) or (3-3-5) is the minimum value for its specific structure. And S can be calculated from the formula (3-1-4) or (3-2-4) or (3-3-4).

In practical application, they all need:

$$\Delta_{pratical} \ge \Delta \qquad (4\text{-}2\text{-}1)$$

The value of parameter $\Delta_{pratical}$ affects the cylinder stroke length and the adjustment efficiency for the lift platform. If it is too large, it is also affecting the minimum step length between the adjacent holes on the guide rails. Whereas, it will cause the operation tolerance small, and maybe make the operation accuracy and difficulty increasing. In order to determine a proper compensation length Δ, we should consider all the errors be introduced by the HACU structure. These mainly include:

1. The manufacturing and assembly errors among the cylinders being used for the HACUs of the same lift platform;
2. The unevenness of the lift platform frame and the adjustment diversity of the support frame among different HACUs of the same lift platform;
3. The non-synchronous working mismatch errors among different HACUs of the same lift platform.

4.3. Other Items for the HACU Design Consideration

Besides all the terms and regulations mentioned above for HACU design, there are many other additional items for the HACU design:

1. Because the length of the up-insert-pin must stride over the two rails, it will burden a large amount of bending moment and shear stress than that of the under-insert-pin (see Figure **1**). It is highly recommended that it should be designed by using a high strength material especially when the lift platform is very heavy or support heavy loads. Alternatively, you can order a special designed cylinder having a rod end piece with thick type eye ring to decrease its stress intensity value.
2. The wide size of the holes on the supporting frame for the under-insert-pin should meet the design term (4) that we have mentioned at chapter 3. It is usually designed as a horizontal arranged ellipse hole on the supporting frame.
3. The diameters of up-insert-pin and under-insert-pin should be a little smaller than that of the cylinder rod end eye ring for being able to pull out or insert in the pins easily and effectively.
4. The mounting style of the cylinder should be chosen as following: both the eye rings of the rod end and the base end should be plain clevis or only that of the base end can be self-aligning clevis. In addition, a supporting bar should be designed to confine the swing range of the cylinder to protect it from lining down during the lift platform is climbing up and down.
5. Because the crews must operate the rod end pins at a high position above the platform when the cylinders stretch out, it is necessary to design some auxiliary parts at the nearby appropriate positions for them to work conveniently. Such as the ladder for human climbing up and the support frames for pins storage etc.
6. In ordinary, an additional circumjacent clearance for the sizes of the holes on the guide rails should be considered for easily pulling out or inserting in the pins. It relies on the specific assembling gaps between the supporting wheels and the guide rails of Figure **1** and their maximum elastic deformations under the service loads of the lift platform.

5. CONCLUSIONS

1. HACU has been proven being a very effective and safety mechanism for the lift platform height-level adjustment. It can continuously adjust the lift platform to its needed working height-level

position along the guide rails in proportion to the minimum step length between the adjacent holes. Its high safety relies on that there are at least one pin insert into the holes on the guide rails to assure the lift platform being firmly supported at its every climbing up and down operation steps. Its disadvantage is that the operator should carry out a series of operation steps at its every working cycle, and this decreases its working efficiency. In addition, if there any demand for long distance climbing, it should to be equipped with long or quick-change coupling junctions for the wires and the hydraulic hoses.

2. Three HACU designing methods have their own advantages in engineering. Designers must consider all the components and their specific construction of the assembling parts (see Figure **1**) to choose an appropriate method for HACU designing.

As for the space launch site projects, there are many layers of lift platforms simultaneously assembled on several paralleled vertical arranged guide rails. In the mean time, the dimensions of the lift platform are usually large. Its weight and working load are usually heavy. So, every lift platform are usually has several HACUs to be working synchronously. For these reasons, many errors are introduced and must be considered for the AHCU design (see chapter 5.2). So, it is recommended to choose method 1 to design the HACUs to compensate these errors and make it easy to operation.

Method 2 and 3 are more suitable for the case that there is only one guide rail mounting on a rigid base structure, or where the errors and non-synchronous working mismatch tolerances of several HACUs are small enough to be accurately controlled and compensated. In this case, we can design the HACU by using circle holes to instead of ellipse holes on the rails. This will rapidly decrease the costs of manufacturing and assembling. The adjacent distance between the holes on the rails is also can be smaller than that of method 1, and the adjustment accuracy of the lift platform height-level can be improved.

3. Three types of HACU design methods and their calculate formulae are also suitable for the lift platform designing of the tower cranes, jack-up drilling rigs and stereoscopic garages etc. If we can improve it to be a self-elevating mechanism by using intelligent control products and by programming it for automatic operation, it will be gotten more widely usage in a broad sense.

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